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OBSERVATION OF 9.0-MICRON LINE EMISSION FROM Ar III IN NGC 7027 AND NGC 6572*

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ABSTRACT

The fine-structure line of Ar III at 1112 cm^{-1} has been observed in the planetary nebulae NGC 7027 and NGC 6572. The measured line intensities are compared with theoretical estimates for these nebulae.

Subject headings: infrared — nebulae

Calculations of Delmer, Gould, and Ramsay (1967) have indicated that certain infrared fine-structure lines of abundant ions in planetary nebulae are observable through the 8–14 μ atmospheric window. Subsequently, fine-structure transitions of Ne II and S IV have been observed (Gillett and Stein 1969; Rank *et al.* 1970). The present paper reports the observation of a third fine-structure line, the $^3P_1$–$^3P_2$ transition in the ground state of Ar III, in the planetary nebulae NGC 7027 and NGC 6572.

The observations were carried out during 1972 July and August at the 120-inch (305-cm) telescope of the Lick Observatory. A tandem Fabry-Perot interferometer (Holtz 1971) was used at a resolution of 0.25 cm^{-1}. The detector viewed a rectangular aperture approximately $4'' \times 10''$, and standard beam-chopping techniques were employed.

Figure 1 shows spectra of NGC 7027 and NGC 6572 in a small interval centered on the frequency of the Ar III fine-structure line. The instrumental resolution and rms noise for a single data point are shown for each spectrum. Doppler shifts of both planetary nebulae were approximately $+0.05$ cm^{-1} and have not been removed from the data.

The best previous value of the $^3P_1$–$^3P_2$ transition frequency of Ar III obtained from ultraviolet transitions is 1112.4 cm^{-1} (Moore 1949). In addition, Bowen (1960) has estimated the frequency 1112.1 cm^{-1} for the transition by using the theory of term and level differences for an isoelectronic sequence (Bowen and Millikan 1924). The Ar III lines in NGC 7027 and NGC 6572 were observed at a rest frequency of 1112.2 ± 0.1 cm^{-1}, which agrees well with the above values. This frequency also agrees with the position of an emission feature observed in NGC 7027 by Rank *et al.* (1970) and tentatively identified as the Ar III line. The Ar III frequency was measured relative to ammonia lines near 1112 cm^{-1} with an absorption cell. The signal-to-noise ratio for the line in NGC 6572 is low. However, the spectrum of NGC 6572 was observed on two separate occasions to have a maximum at the frequency of the Ar III line in NGC 7027. Hence there is little doubt of the presence of this line in NGC 6572. In addition, a search for an Ar III line in the planetary nebula NGC 7662 yielded negative results consistent with those given by Holtz, Geballe, and Rank (1971) for that object. The line in NGC 7027 appears somewhat broader than the instrumental

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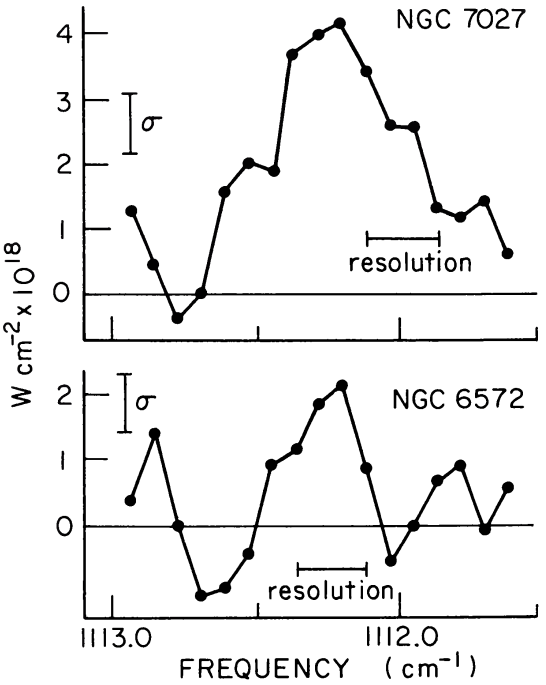

FIG. 1.—Spectra of NGC 7027 and NGC 6572 at the frequency of the Ar III fine-structure transition. *Dots,* observed spectra; σ represents the probable error for a single data point.

transmission, although the additional breadth could be attributed to noise fluctuations. Known velocity differences in the nebula would produce a line of width approximately half the instrumental width of 0.25 cm^{-1}.

Measured intensities for the Ar III lines in NGC 7027 and NGC 6572, as well as the intensities predicted by Delmer *et al.* (1967), are shown in table 1. The observed intensities were calibrated from continuum measurements on α Sco, using the photometric data of Gehrz and Woolf (1971) and Low (1971), and from observations of the 951.5 cm^{-1} S IV line in NGC 7027, whose strength is given by Holtz *et al.* (1971) and by Gillett, Merrill, and Stein (1972). Column (3) gives estimates of the total line intensities in the two nebulae, on the assumption that the effective Ar III diameters of NGC 7027 and NGC 6572 are 12″ and 9″, respectively. The values in column (3) are thought to be accurate to within 50 percent for NGC 7027 and to within a factor of 2 for NGC 6572. It should be noted that for NGC 7027 we have subtracted the average off-line intensity of $\sim 1.0 \times 10^{-18}$ W cm^{-2} observed in figure 1 from the intensity at 1112.2 cm^{-1} to obtain the value of the line intensity in column (2) of table 1. No continuum was detected from NGC 6572. The effective bandwidth of the

TABLE 1

INTENSITY OF Ar III $^3P_1$–$^3P_2$ LINE AT 1112.2 CM^{-1}

Planetary Nebula (1)	Observed Intensity Within Beam (W cm^{-2} × 10^{17}) (2)	Total Line Intensity (W cm^{-2} × 10^{17}) (3)	Intensity Predicted by Delmer *et al.* (1967) (W cm^{-2} × 10^{17}) (4)
NGC 7027	0.3	1.0	7
NGC 6572	0.2	0.4	7

system for continuum radiation was 0.6 cm^{-1} due to transmission outside the 0.25 cm^{-1} bandpass. Hence, the continuum from NGC 7027 at 9.0 μ as calculated from our observations is $\sim 6 \times 10^{-16}$ W cm^{-2} μ^{-1}, which is in good agreement with the measurements of Gillett *et al.* (1972).

Column (4) of Table 1 lists the predictions of Delmer *et al.* (1967) for the Ar III line intensity in the two nebulae. These estimates are reduced by a factor of 2.3 if one substitutes the value of the $^3P_1$–$^3P_2$ collision strength for Ar III calculated by Blaha (1969) for the value they used. In that case the values of Delmer *et al.* (1967) are too large by factors of 3 and 8.5 for NGC 7027 and NGC 6572, respectively. Flower (1970*a*) has estimated the intensity of the Ar III line in three planetary nebulae, of which only NGC 7662 was observed by us. (These estimates have been revised by Flower 1970*b* to allow for an error in the original calculation.) If his mean predicted line intensity ratio Ar III/Hβ for the three nebulae is used to obtain Ar III line intensities for NGC 7027 and NGC 6572, the values obtained are in moderate agreement with our observed values.

The generally low intensities of the 951.5 cm^{-1} S IV line in planetary nebulae (Holtz *et al.* 1971; Gillett *et al.* 1972) could be attributed to the underabundance of the ionic species S IV. In the present case, however, the abundance of Ar III was assumed by Delmer *et al.* (1967) to be known from observations of an optical ($\sim$7500 Å) line of the same ion, and was used by them to estimate the 1112.2 cm^{-1} line strength. Such an estimate is sensitively dependent on the assumed electron temperature and on the collision strengths for the infrared and optical transitions, the latter of which has only been roughly estimated (Delmer *et al.* 1967). That the estimates of Delmer *et al.* (1967) differ substantially from our measured values indicates that the values of the electron temperatures as well as the collision strength for the optical transition may not be accurately known. In addition, the large range in the deviations between predictions and observations for NGC 7027 and NGC 6572 suggests that one may also have to treat the temperature and density nonuniformities in each planetary nebula in order to obtain more accurate predictions of fine-structure line intensities.

The abundance of the ionic species Ar III can be calculated using equations (11) and (A10) in Delmer *et al.* (1967). The values obtained relative to hydrogen are 7×10^{-7} for NGC 7027 and 9×10^{-7} for NGC 6572. If the ratio A/H is 1×10^{-5} in planetary nebulae (Aller and Czyzak 1968), the fractional ionizations of Ar III are 7 and 9 percent in NGC 7027 and NGC 6572, respectively. Since collision strengths have been calculated more accurately for the infrared fine-structure transitions than for the optical transitions, and since the 1112.2 cm^{-1} line intensity is much less sensitive to the electron temperature than is the optical line intensity, the above values should be more accurate than previous estimates of the abundances of Ar III in these nebulae.

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